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DOCUMENTATION OF THE SPACE STATION/AIRCRAFT ACOUSTIC APPARATUS

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DOCUMENTATION OF THE SPACE STATION/AIRCRAFT ACOUSTIC APPARATUS

BY

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SUMMARY

This paper documents the design and construction of the Space Station/Aircraft Acoustic Apparatus (SS/AAA). Its capabilities both as a space station acoustic simulator and as an aircraft acoustic simulator are described. Also indicated are the considerations which ultimately resulted in "man-rating" the SS/AAA. In addition, the results of noise surveys and reverberation time and absorption coefficient measurements are included.

INTRODUCTION

Although the space station configuration has not been finalized, many potential problem areas have been documented and will need to be addressed. One of these areas concerns the acoustic environment to which the occupants will be subjected. How this environment will affect habitability and the accomplishment of the control tasks should be addressed.

The NASA Langley Research Center has built a Space Station/Aircraft Acoustic Apparatus as a man-rated dual purpose simulator. When configured as a space station, research on human response to expected space station acoustic environments will be conducted. When configured as a modern aircraft interior, research on human response to expected aircraft acoustic environments will be conducted.

The purposes of this paper are: 1) to document the design and construction of the SS/AAA; 2) to show how SS/AAA was "man-rated;" and 3) to show results of noise surveys within the SS/AAA when configured as a space station.

DESIGN AND CONSTRUCTION

On February 29, 1984 a work request was initiated to obtain assistance from the Engineering Divisions on the design and construction of the SS/AAA. Preliminary designs for a convertible space station/aircraft simulator were completed. Prior to letting a contract to build the simulator, its projected location of Room 136 in Bldg. 1208 was changed in August 1984 to Room 139 in Bldg. 1208 necessitating not only a redesign of the simulator but also the removal of the man-rated facility known as the Interior Effects Room and the replacement of its wooden floor with a concrete floor. Concurrent with the design and construction, a steering committee (including the LaRC Safety Manager) was created on March 13, 1984 to assist in the Preliminary Design, Final Design, and Integrated Systems Reviews of the SS/AAA. The simulator was completed and man-rated on January 21, 1986. Details of the design and construction follow.

Design

The overall design of the SS/AAA consisted of a wood structure with appropriate heating and cooling, electrical wiring, and acoustic simulation.

Wood Structure Design

The concept for the design of the SS/AAA was to have dimensions to not only approximate the expected size of a space station module, but also be suitable to install the actual interior of a modern jet aircraft. The overall dimensions are shown in figure 1. The interior height is approximately 8 feet. Design details are shown in figures 2-5. Figure 2 is an isometric view indicating how the ribs, stringers, and paneling are assembled. Figure 3 is a cross-section view showing the primary rib, fasteners, inner and outer surfaces, as well as the cross-section dimensions. The sketch on the left of the figure indicates how the front and rear panels are connected to the floor supports and ribs. Figure 4 shows a front view and indicates the main entrance opening for a 36 inch by 78 inch standard door. Also shown are the 2 inch by 4 inch stiffeners and plywood paneling. Figure 5 shows a side view and indicates the rib spacing as well as the overall interior length. Figure 6 shows the emergency rear exit, consisting of a standard steel door of 32 inches by 78 inches. It also shows the cinder block wall of the side of Building 1208.

Heating, Cooling, and Electrical Design

The heating and cooling system consisted of modifying the existing room heating and cooling ducts and adding appropriate temperature and humidity controllers in the SS/AAA. Four room intake grills located down the center and four return grills, two on either side, front and rear, were provided for air distribution. Adequate supply for both heating and cooling was available.

The electrical system consisted of lighting and wall receptables. The lighting was five sets of four fluorescent lamps down the center of the ceiling of the SS/AA. The undersides of these fixtures had a diffuser covering. Two dimmer switches, each controlling 10 lamps, were located on the front wall near the door. Six dual receptables were placed along each side wall, about two feet above the floor.

Acoustic Design

The acoustic system consisted of multiple loudspeakers mounted on the outside of the SS/AAA plus their control systems. Figure 7 shows the circuitry of a typical loudspeaker installation. The attenuators, noise limiters, and amplifiers are in the control room, Room 143 of Bldg. 1208. Sounds from the loudspeakers are picked up by the monitor microphone located in the ceiling of the SS/AAA and converted to an electrical signal which is recorded on a graphic level recorder and is directed to the noise limiter. Excessive noise (greater than that programmed) would cause the limiter to function and cut off the signal to the amplifier. To obtain uniform sound within the SS/AAA, 24 loudspeaker systems consisting of 8 inch woofers and 1.5 inch low mass tweeters were located at 6 longitudinal positions and at four radial positions.

Construction

Figures 8-14 shows various stages of construction. Figures 8 and 9 are interior views looking forward and aft respectively. Figure 10 is an exterior view looking toward the rear. Figure 11 shows the front of the SS/AAA and indicates its closeness to the front wall of the room in which it was constructed. Figure 12 shows the speaker units mounted on the exterior of the SS/AAA with the camera angle looking toward the rear. Figures 13 and 14 show the final configuration and are similar in perspective to figures 8 and 9, respectively. Dummy mock-ups of consoles are shown.

MAN-RATING

Safety considerations caused modifications to three rooms in Building 1208. The least modified was room 136 adjacent to room 138. The door between the rooms was removed for easier emergency egress. In room 138, appropriate exit lights were installed. Room 139 which encloses the SS/AAA (Room 140) had a number of modifications. First, the Interior Effects Room was removed. The resulting hole in the floor was replaced with a reinforced concrete floor. The emergency exit door was reversed so that it opened outward. Room 139 already had exit lights and sprinklers, but emergency lights and smoke detectors had to be added. In addition, the floor and walls were painted with fire-resistant paint.

The SS/AAA was constructed in place in room 139 from plywood and wood ribs and stringers, all treated to be fire-resistant. It had conventional steel doors, a 36" x 78" door in front and a 32" x 78" door in the rear on the right side. All painting utilized fire-resistant paint. The electrical work, and heating and ventilation installations met the building codes. In addition to the smoke detectors and emergency lights, a two-way communication system and a TV monitor were installed. A control monitor microphone was installed to prevent any interior noise levels greater than programmed levels. Programmed levels could be up to OSHA standards to 90 dB(A) for either sinusoidal and/or shaped random spectra.

Since the SS/AAA is man-rated for research, and was built in the volume formerly occupied by the man-rated Interior Effects Room, approval for research and a recertification of the room was required. Approval for research required approval of a revised protocol (74-2) by the LaRC Director. Recertification also required approval by the LaRC Director. A memorandum dated December 18, 1985 was forwarded to the director through the Executive Safety Board. The Director signed his approval on January 21, 1986, for both the protocol and recertification of the SS/AAA.

NOISE SURVEYS

Three noise surveys were made in the SS/AAA as baseline data. One survey consisted of determining the distribution of random noise levels in the empty shell. Another survey consisted of measuring the reverberation times and absorption coefficients with mock-up consoles installed. The third survey consisted of determing the distribution of both random and sinusoidal noise levels with the mock-up consoles installed.

Random Noise Survey

A grid system was located on the floor (figure 15) so that acoustic data could be obtained and plotted for many discrete points. The nine locations across (A-G) were at about 16-1/2 inch increments and the 11 stations from front to rear (1-11) were at 24 inch increments, with no location close to a wall. Spectral and overall noise levels were obtained for a "pink" noise input at each location, A1 through G11, for elevations of 48 inches and 64 inches above the floor, and for locations B1 through F11 for an elevation of 82 inches above the floor. Although the spectra varied considerably between 1/3 octave bands for many data points, the overall and A weighted levels at each location were within $\pm$1-1/2 dB of the mean. The measurements of A weighted and overall dB levels are shown as three-dimensional views in figure 16.

Reverberation Times and Absorption Coefficients

After dummy consoles were installed (figures 13 and 14) it was appropriate to measure reverberation times and absorption coefficients in the SS/AAA. Two methods were used. In one method, a reverberation timer (Communications Company, Inc.) with its included filters measured the reverberation time and the inferred absorption coefficients for various octave bands. The second method consisted of measuring the space averaged sound pressure level, SPL, from a calibrated sound power source (B&K Model 4204) and calculating the absorption coefficients and correspondingly the inferred reverberation times. The relationship to infer the absorption coefficient from a measured reverberation time is

$$\alpha = \frac{.161\ V}{ST}$$

where

T = reverberation time, sec
V = volume, m^3 ($42.5\ m^3$)
S = surface area, m^2 ($82.1\ m^2$)
α = absorption coefficient

The relationships used with the calibrated sound source were

$$\alpha = \frac{4}{S} 10^{\frac{1}{10}[L_w - SPL - W_r]}$$

SPL = space averaged sound pressure level

$$T = \frac{0.161V}{S\alpha}$$

and $W_r = 10 \log_{10} \left(1 + \frac{S\lambda}{8V}\right)$ where

L_W = sound power level

W_r = Waterhouse correction

λ = acoustic wave length, m

The results of these measurements and calculations are shown in the following table:

Reverberation Times and Absorption Coefficients

Frequency Band, Hz	Reverberation Meter		Sound Power Source Including Waterhouse Correction	
	T	α	T	α
125	0.74	0.11	0.21	0.24
250	0.58	0.14	0.33	0.18
500	0.84	0.10	0.78	0.11
1000	1.15	0.07	1.15	0.07
2000	1.14	0.07	1.07	0.08
4000	----	----	0.76	0.11
8000	----	----	0.40	0.21

Good agreement was obtained in the mid-frequency range (500-2000 Hz) and poor agreement was seen at low frequencies where the acoustic modal density is low and reverberation time is of doubtful validity.

Random and Sinusoidal Noise Levels with Dummy Consoles Installed

Random Measurements

After dummy consoles were installed in the SS/AAA, noise measurements in neither the A and G columns nor the 82 inch elevation could be made (figure 15). Thus measurements were made using pink noise for stations B1-F11 at the 64 inch elevation. The overall and A weighted measurements are shown in figure 17 and are compared to the results obtained with the empty SS/AAA (shell). It may be noted that the SPL, sound pressure level, changed very little from station to station. However, in the shell, the SPL's tend to be higher near the center of the shell whereas with the dummy consoles installed, the center tends to have lower SPL's compared to the sides.

Sinusoidal Measurements

Prior to conducting sinusoidal noise studies in the SS/AAA, calculations were made to determine resonant frequencies. Since no exact calculation could be made for the particular shape of the SS/AAA, approximation of the frequencies were made using a formula that is normally used for a volume bounded by rectangular sides. The formula used is

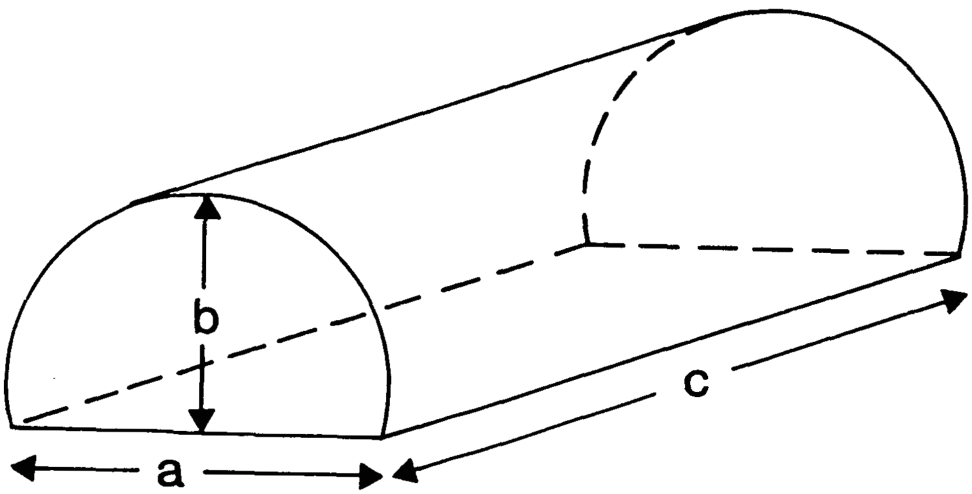
$$f = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{k}{c}\right)^2}$$

where f = Hz

c = speed of sound, ft/sec (1100 ft/sec)

m,n,k = modes in the a,b,c directions as shown in sketch

a,b,c = shell dimensions, ft. (11.1, 8, 23.4 ft.)



Thus only approximate frequencies were calculated for the various modes. It may be noted that the lowest frequency (m=0, n=0, k=1) was calculated to be 23.5 Hz with the standing wave from front to rear of the SS/AAA and no standing waves across or up and down. The lowest side-to-side standing wave (m=1, n=0, k=0) was 49,5 Hz and the lowest vertical standing wave (m=0, n=1, k=0) was 61.1 Hz. The measured resonant frequencies obtained experimentally were 58, 80, 103, 138, 215, 231, and 380 Hz. Although there were other resonances, they appeared heavily damped and were not investigated. The data obtained at the various grid locations were utilized in a computer program to obtain sound contour plots. Figure 18 shows lines of constant SPL for the overall condition for the resonant frequency of 58 Hz. Figure 19 shows the constant contour lines for the overall SPL for the resonant frequency of 80 Hz. As the frequency is increased, more and more lines of constant amplitude occur indicating the presence of higher order modes. It should be noted that these contours apply only at the 64 inch elevation and that the grid layout of B1-F11 is really the central part of the SS/AAA. The measurements at the B and F locations are well inside the outer boundaries made up of the dummy consoles.

CONCLUDING REMARKS

The design and construction of a SS/AAA, Space Station/Aircraft Acoustic Apparatus, have been documented and man-rating has been discussed. In addition, the results of three SS/AAA interior noise tests: 1) the distribution of noise levels when excited by pink noise; 2) reverberation times and absorption coefficients for various octave band frequencies; and 3) the distribution of noise levels for both sinusoidal and pink random noise inputs after installation of dummy consoles were presented.

TABLE

Calculated Resonant Frequencies

m	n	k	f, Hz	m	n	k	f, Hz	m	n	k	f, Hz	m	n	k	f, Hz
0	0	0	0.0	1	0	0	49.5	2	0	0	99.1	3	0	0	148.6
0	0	1	23.5	1	0	1	54.8	2	0	1	101.8	3	0	1	150.5
0	0	2	47.0	1	0	2	68.3	2	0	2	109.7	3	0	2	155.9
0	0	3	70.5	1	0	3	86.1	2	0	3	121.6	3	0	3	164.5
0	0	4	93.9	1	0	4	106.2	2	0	4	13.65	3	0	4	175.8
0	1	0	68.8	1	1	0	84.7	2	1	0	120.6	3	1	0	163.7
0	1	1	72.7	1	1	1	87.9	2	1	1	122.9	3	1	1	165.5
0	1	2	83.3	1	1	2	96.9	2	1	2	129.4	3	1	2	170.4
0	1	3	98.4	1	1	3	110.2	2	1	3	139.7	3	1	3	178.3
0	1	4	116.4	1	1	4	126.5	2	1	4	152.9	3	1	4	188.8
0	2	0	137.5	1	2	0	146.2	2	2	0	169.5	3	2	0	202.0
0	2	1	139.5	1	2	1	148.0	2	2	1	171.1	3	2	1	204.0
0	2	2	145.3	1	2	2	153.5	2	2	2	175.9	3	2	2	208.0
0	2	3	154.5	1	2	3	162.2	2	2	3	183.5	3	2	3	214.0
0	2	4	166.5	1	2	4	173.7	2	2	4	193.8	3	2	4	223.0
0	3	0	206.2	1	3	0	212.0	2	3	0	229.0	3	3	0	254.0
0	3	1	207.6	1	3	1	213.0	2	3	1	230.0	3	3	1	255.0
0	3	2	211.5	1	3	2	217.0	2	3	2	234.0	3	3	2	259.0
0	3	3	218.0	1	3	3	224.0	2	3	3	239.9	3	3	3	264.0
0	3	4	226.6	1	3	4	232.0	2	3	4	247.0	3	3	4	271.0
0	4	0	275.0	1	4	0	279.0	2	4	0	292.0	3	4	0	313.0
0	4	1	276.0	1	4	1	280.0	2	4	1	293.0	3	4	1	314.0
0	4	2	279.0	1	4	2	283.0	2	4	2	296.0	3	4	2	316.0
0	4	3	284.0	1	4	3	288.0	2	4	3	300.0	3	4	3	320.0
0	4	4	291.0	1	4	4	295.0	2	4	4	307.0	3	4	4	326.0

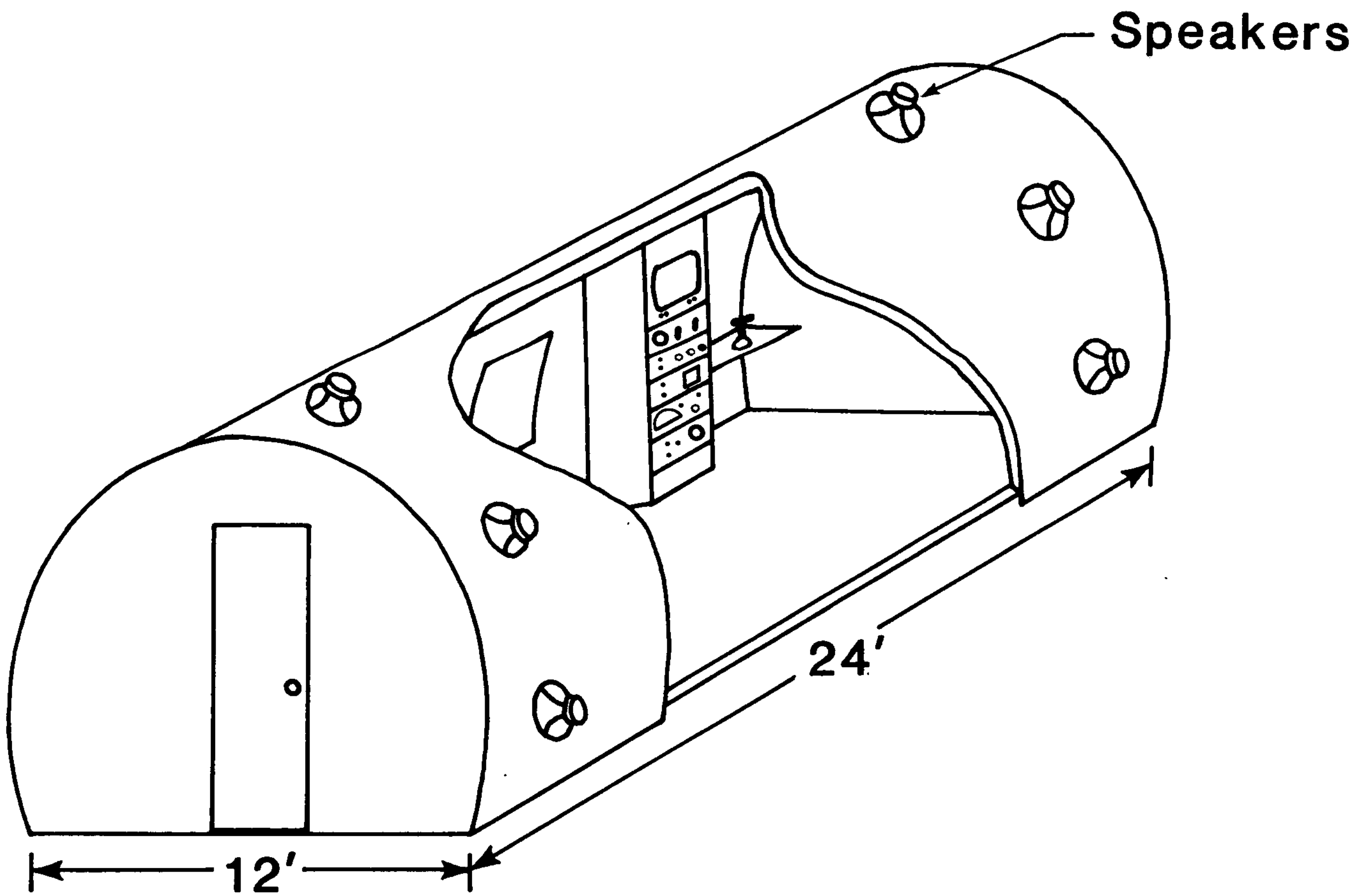


Figure 1.- Isometric view of space station/aircraft acoustic apparatus concept.

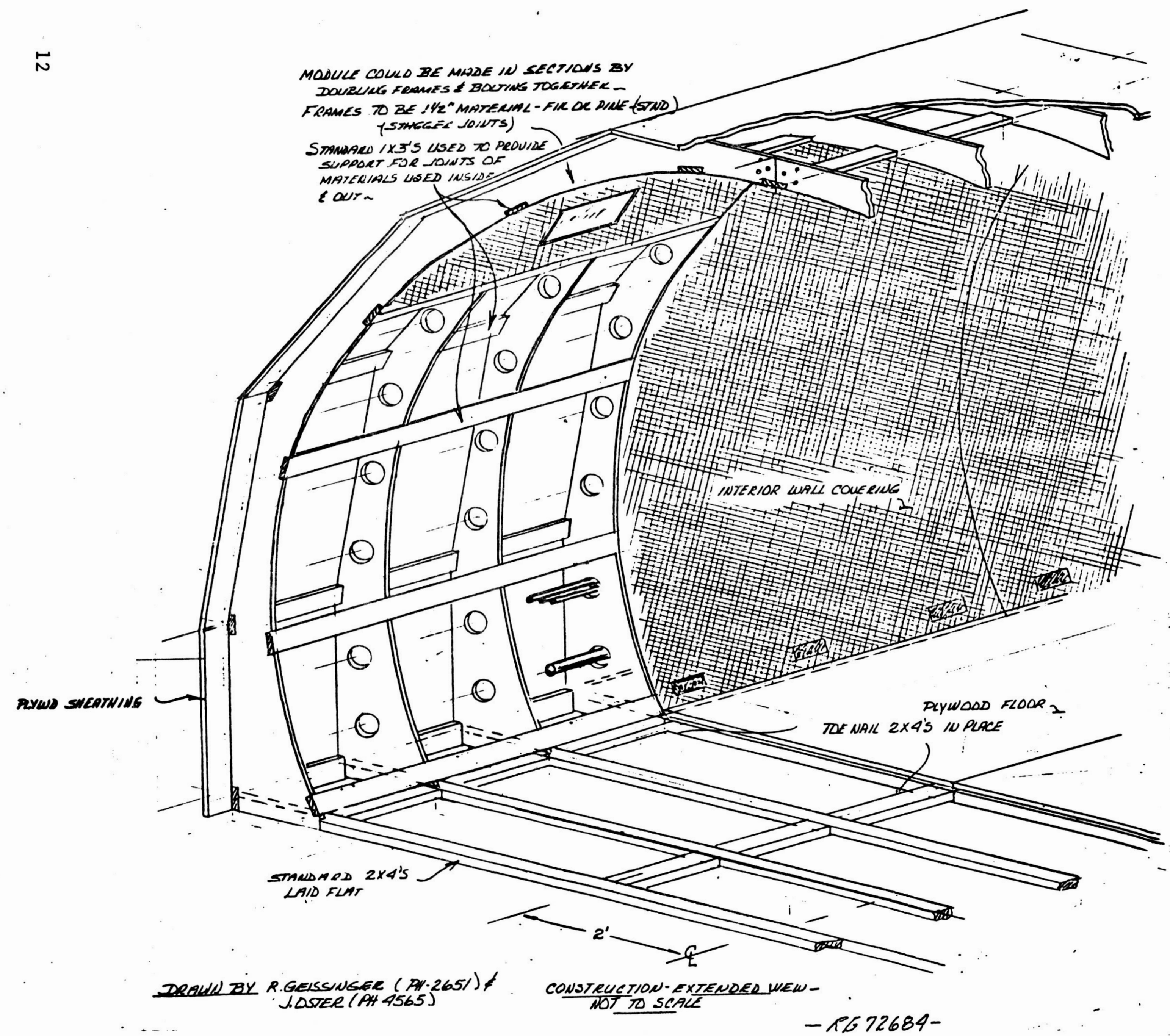


Figure 2.- Isometric view of construction.

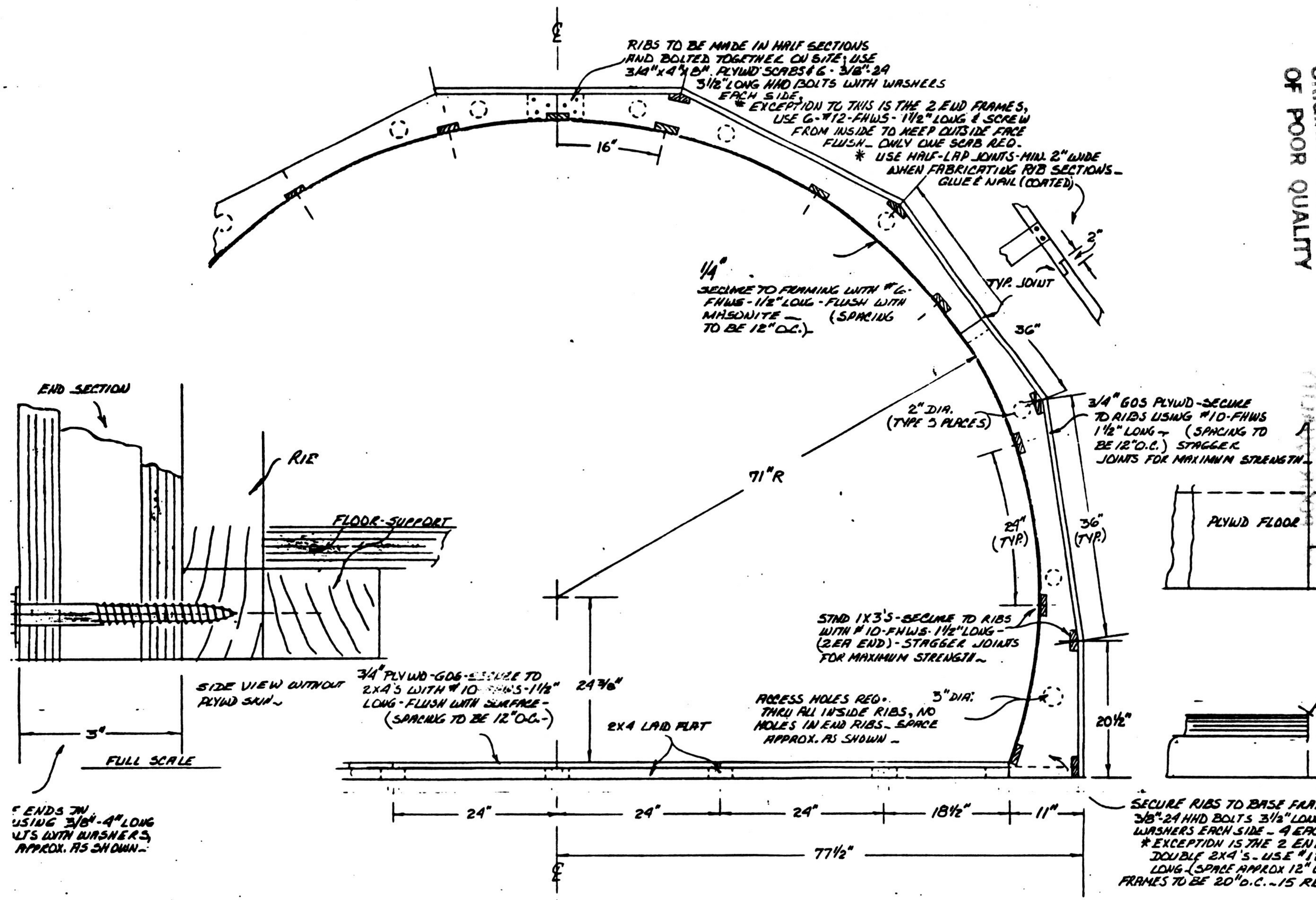


Figure 3.- Mid-section view of details of the SS/AAA.

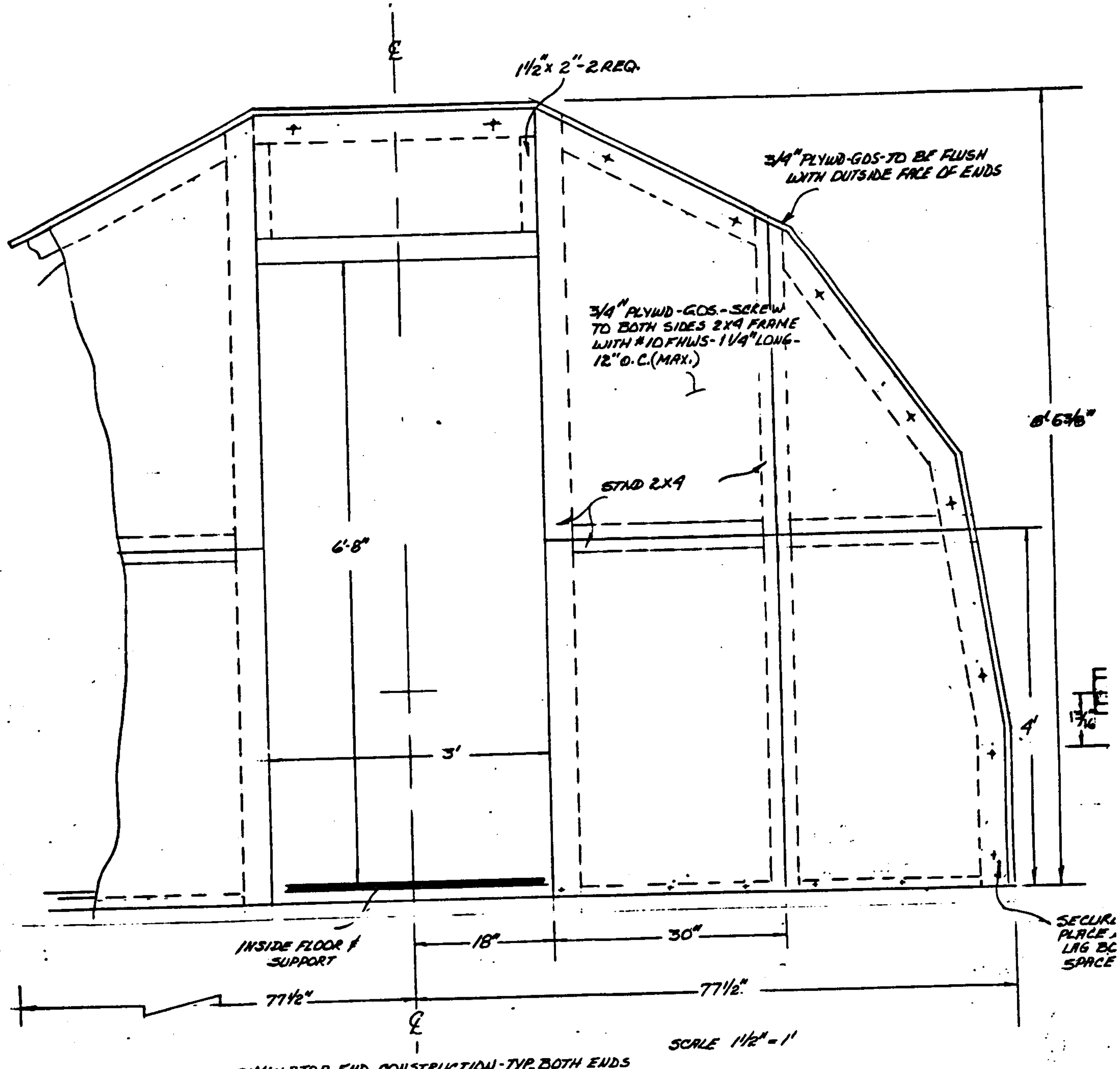


Figure 4.- Front end construction of the SS/AAA.

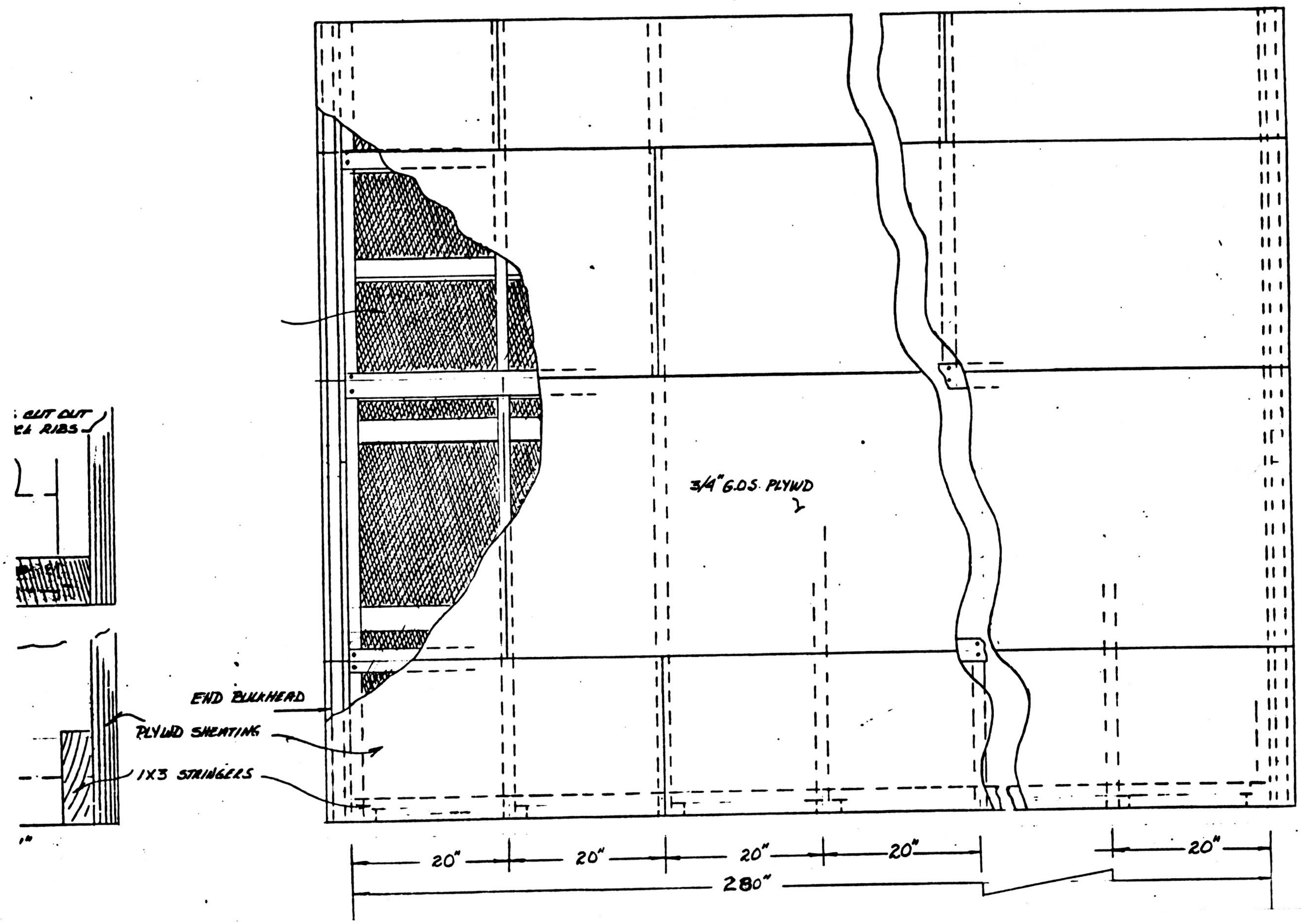


Figure 5.- Side view of the SS/AAA.

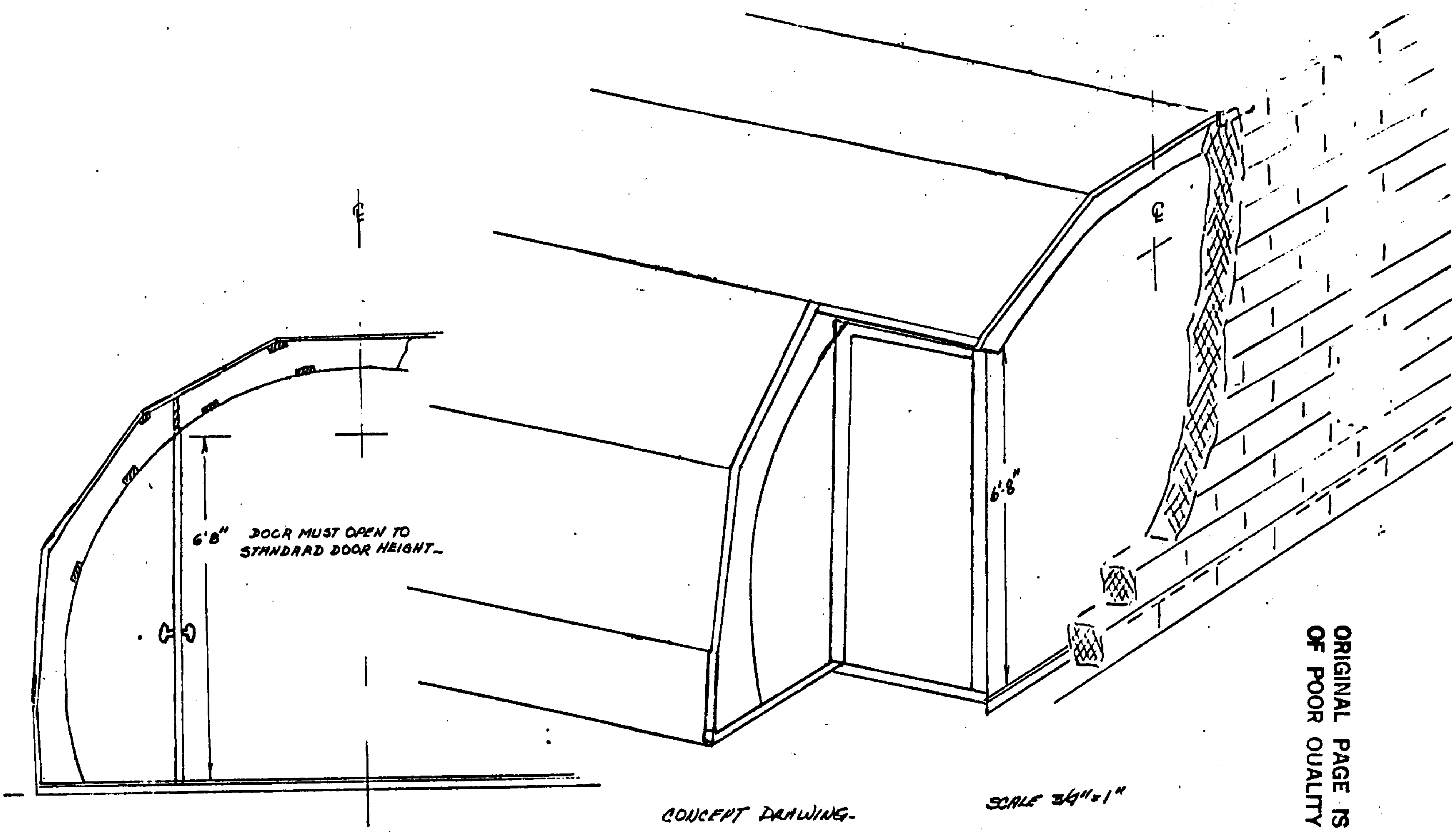


Figure 6.- Isometric view of rear emergency door indicating proximity to the building rear wall.

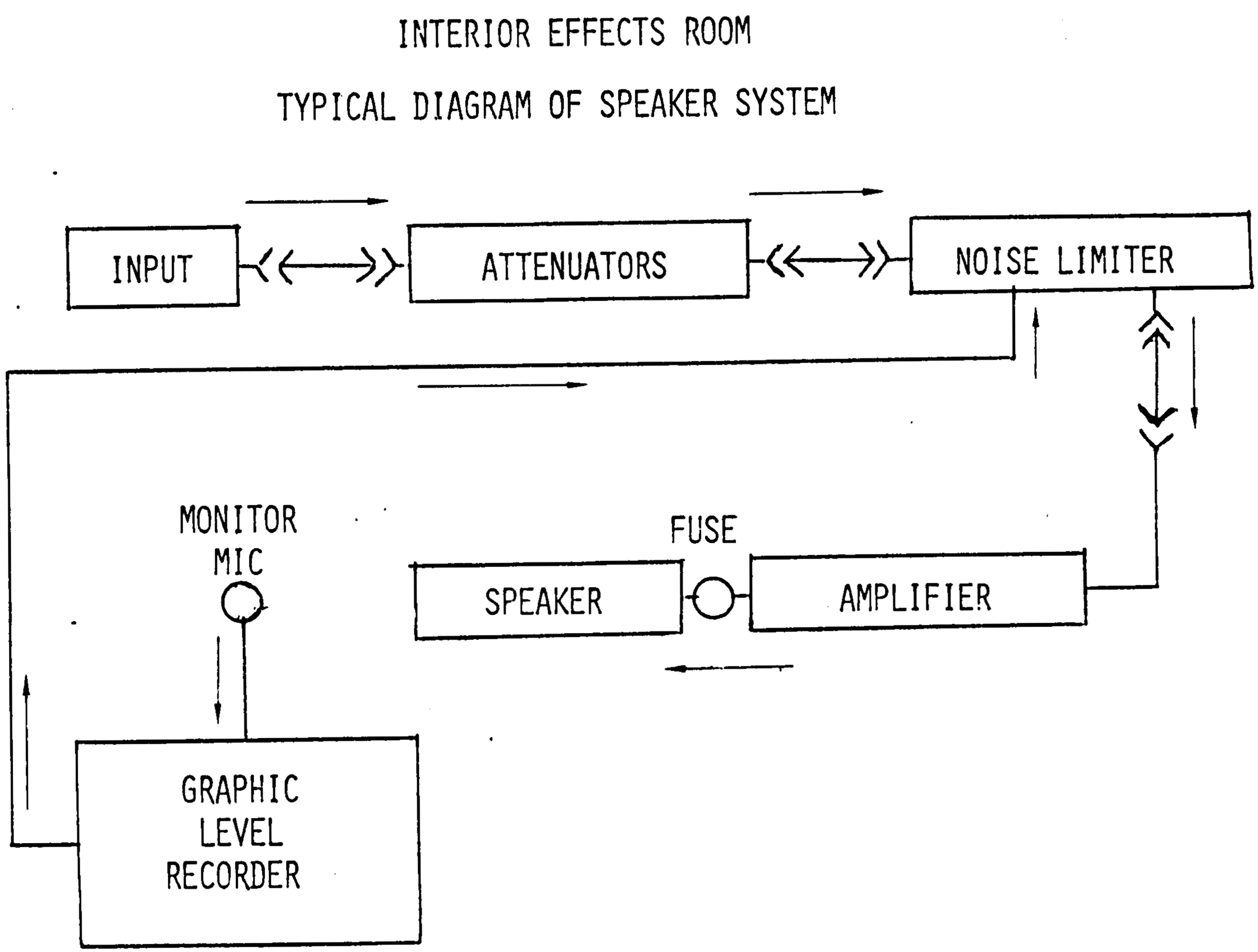


Figure 7.- Typical diagram of the sound system of the SS/AAA.

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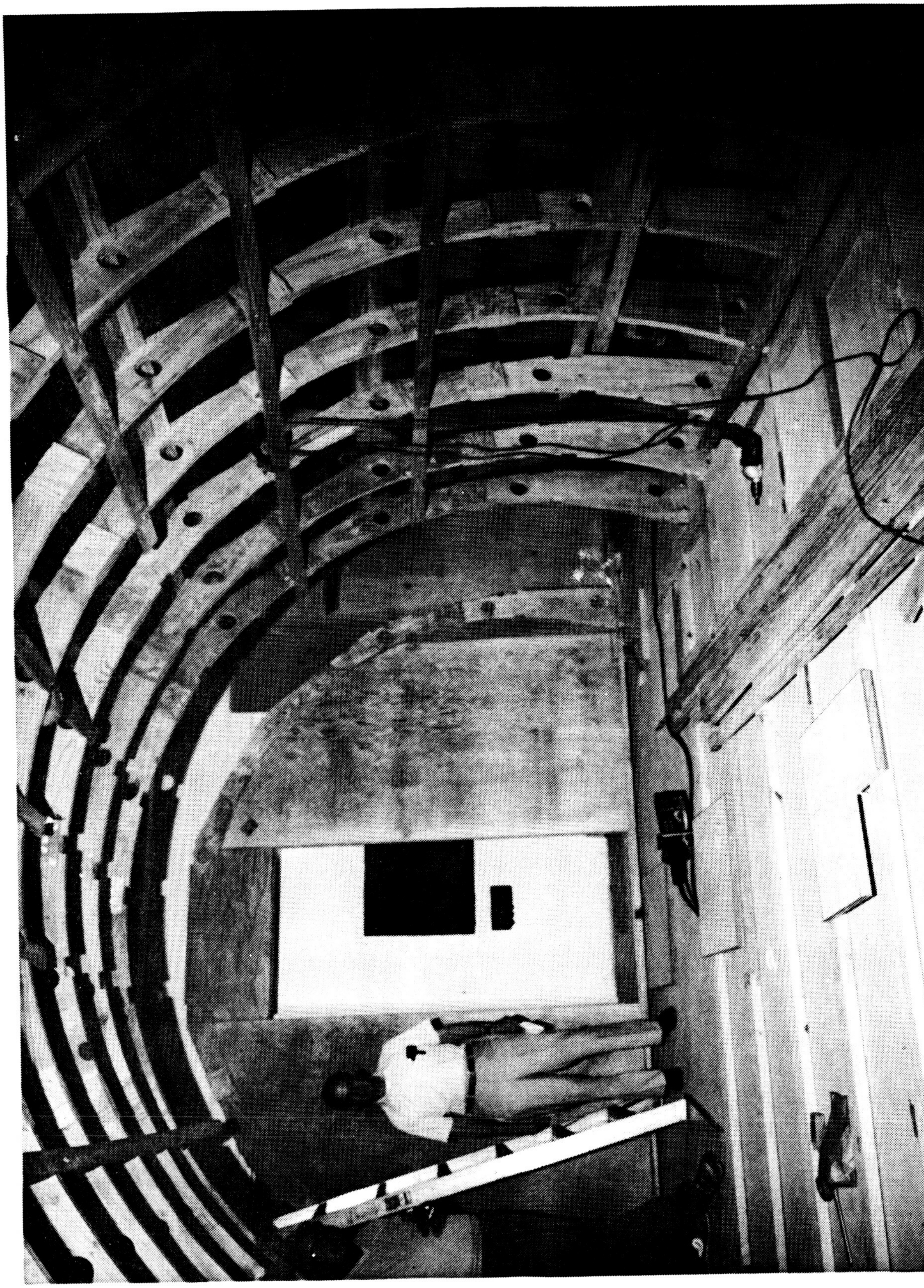

Figure 8.- View toward the front of the SS/AAA during construction.

Figure 9.- View toward the rear of the SS/AAA during construction.

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Figure 10.- Exterior view toward the rear of the SS/AAA during construction.

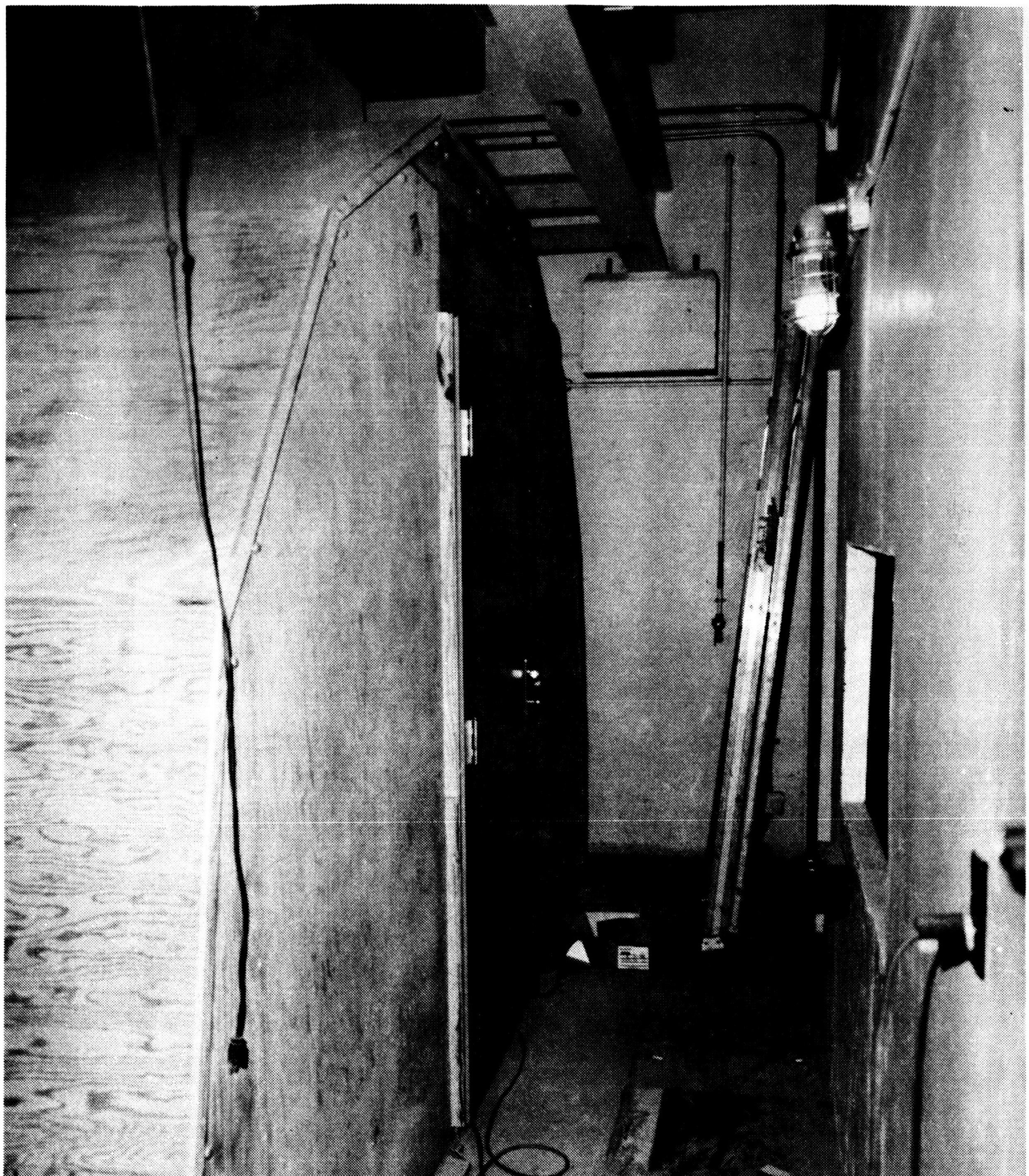

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Figure 11.- Exterior view across the front of the SS/AAA during construction.

Figure 12.- Exterior view toward the rear of the SS/AAA showing one elevation of speakers.

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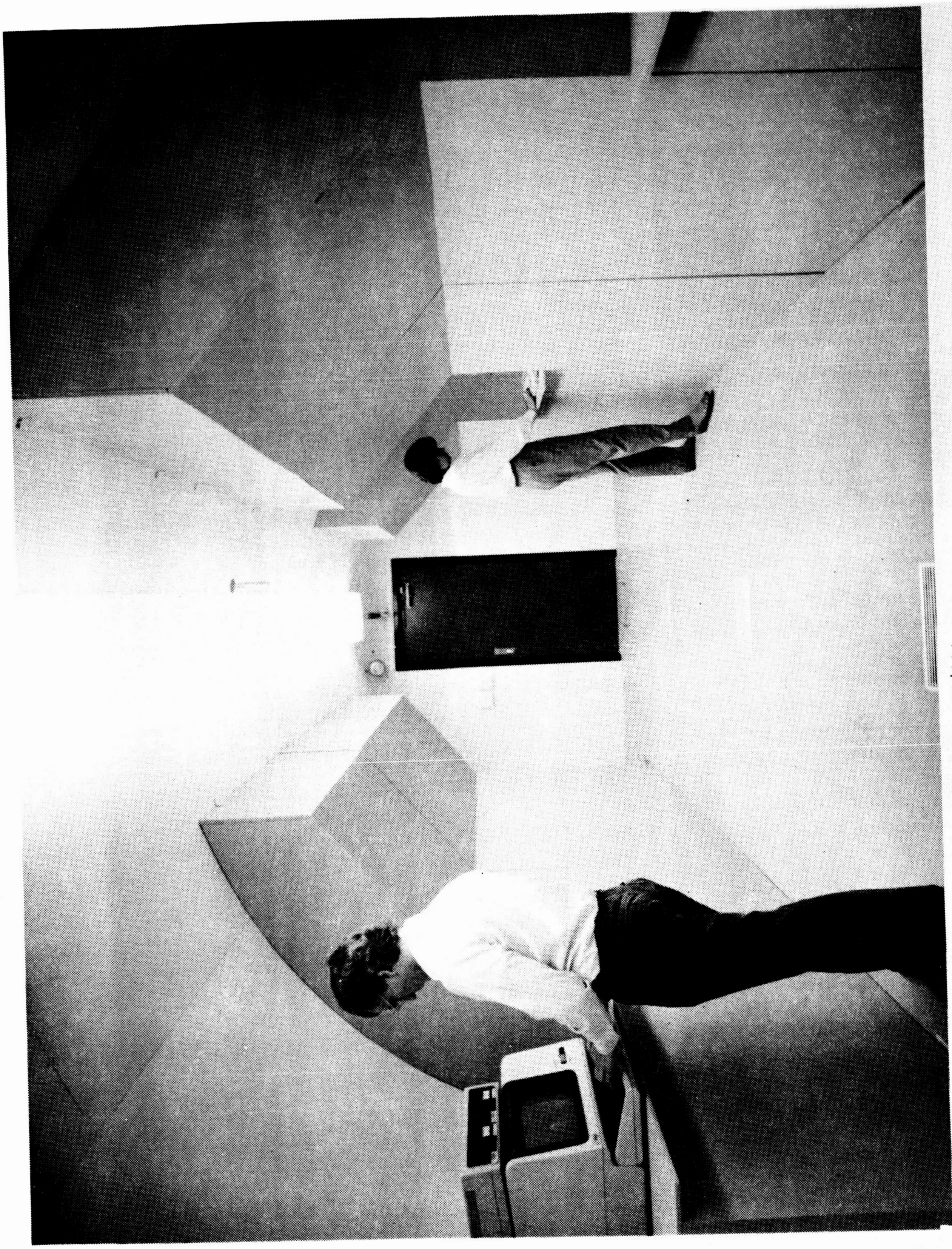

Figure 13.- View toward the front of the SS/AAA.

Figure 14.- View toward the rear of the SS/AAA.

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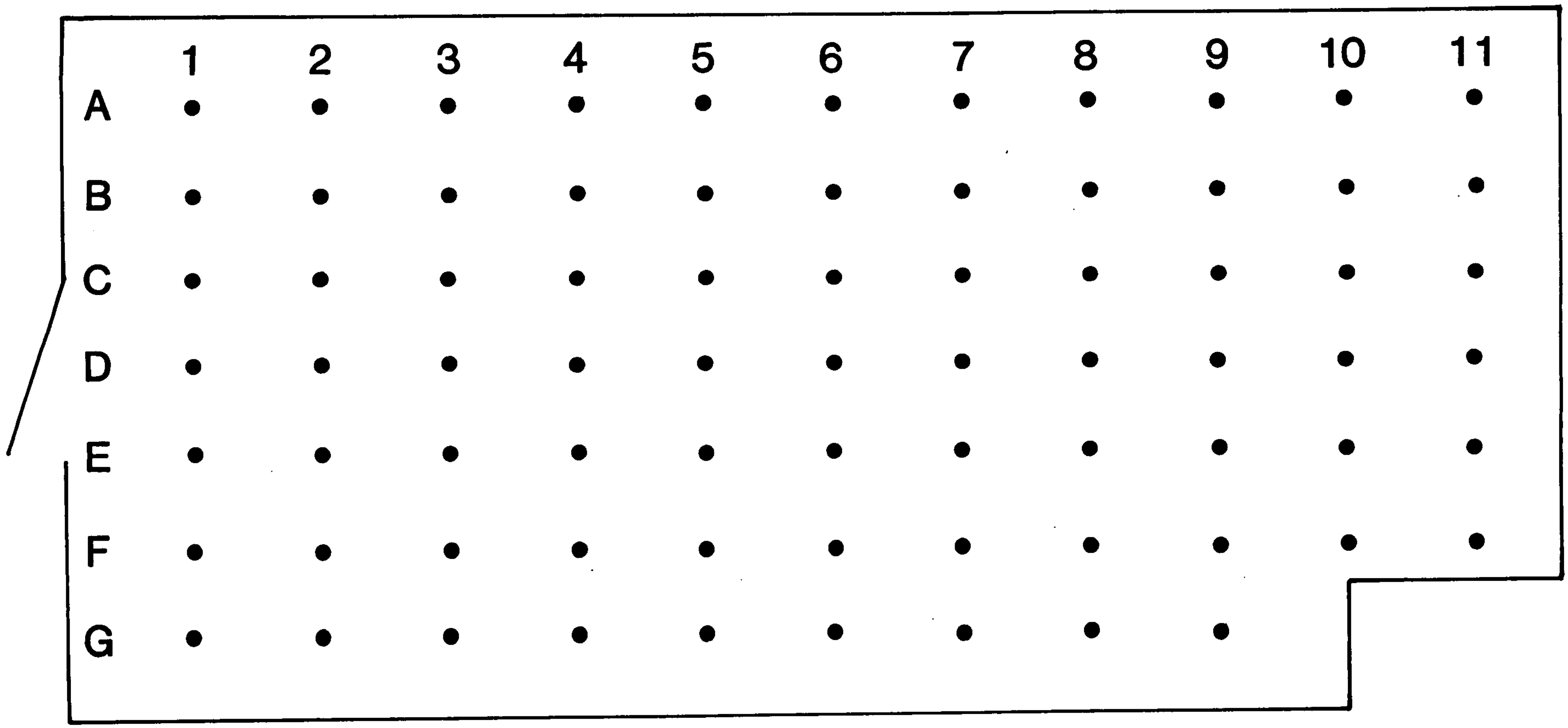

Figure 15.- Grid System on the floor of SS/AAA for locating microphones.

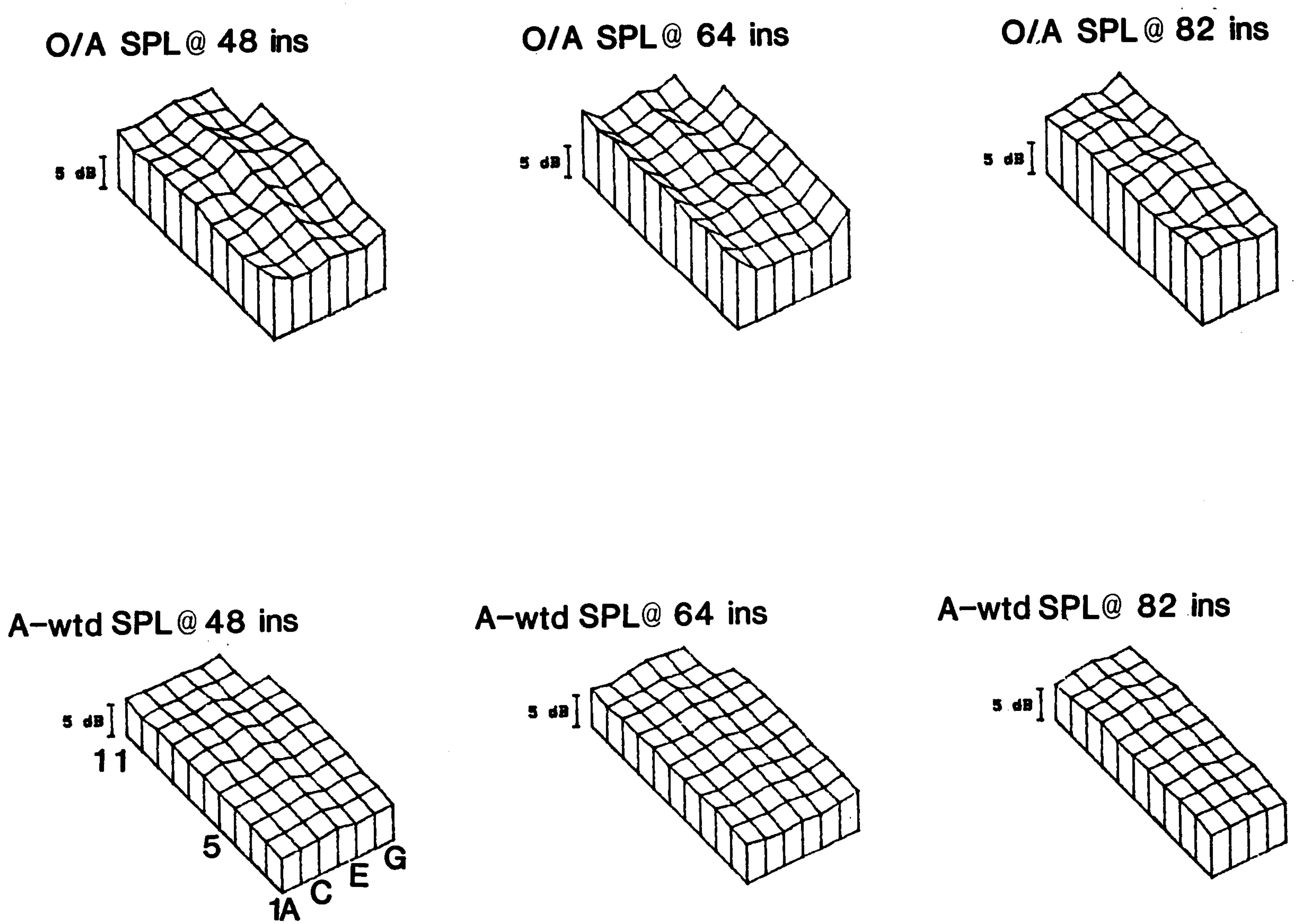

Figure 16.- Overall and A weighted sound pressure levels for three elevations in the empty SS/AAA.

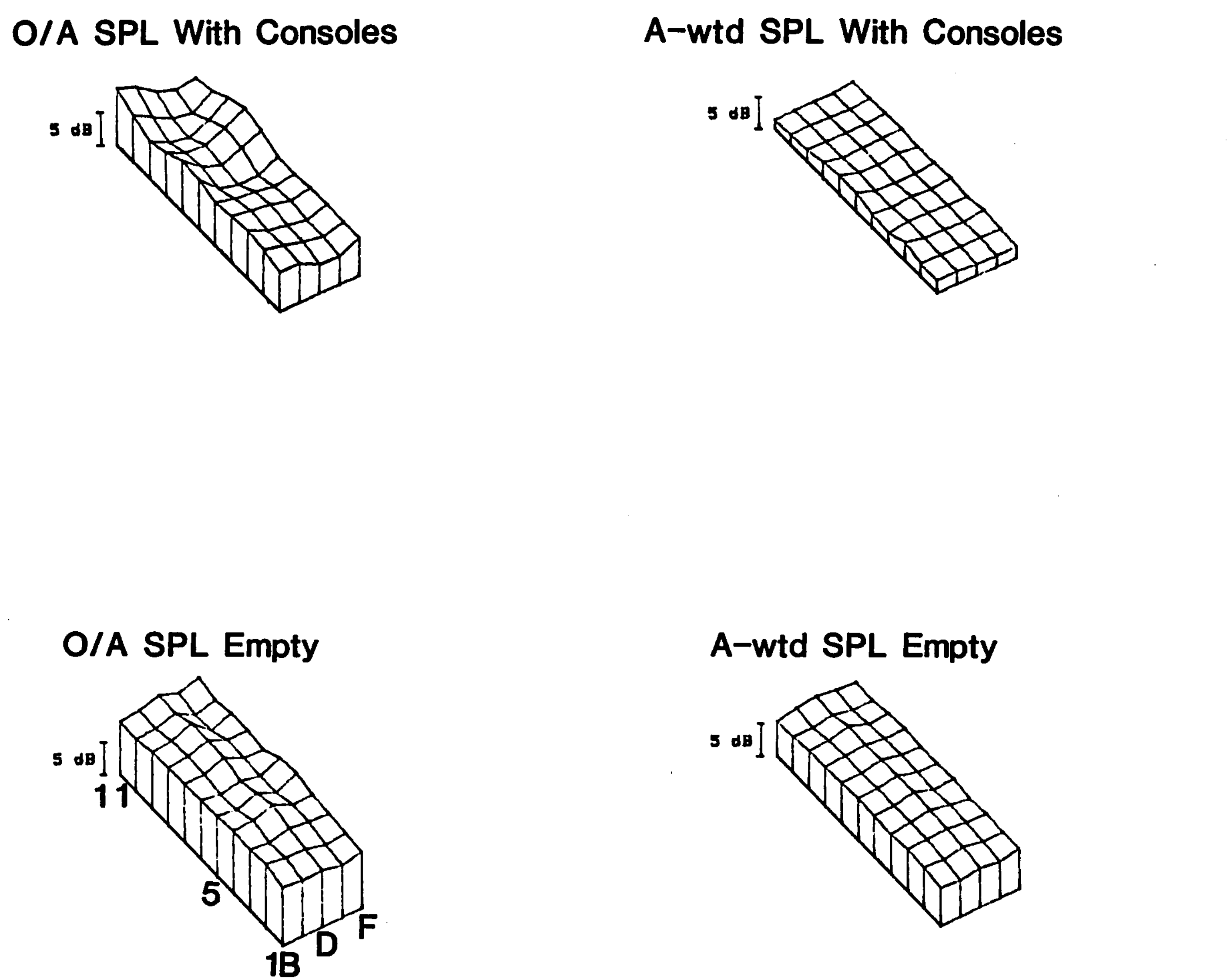

Figure 17.- Comparison of sound pressure levels in the SS/AAA with dummy consoles with the levels measured in the empty shell of the SS/AAA. 64" elevation, stations B1-F11.

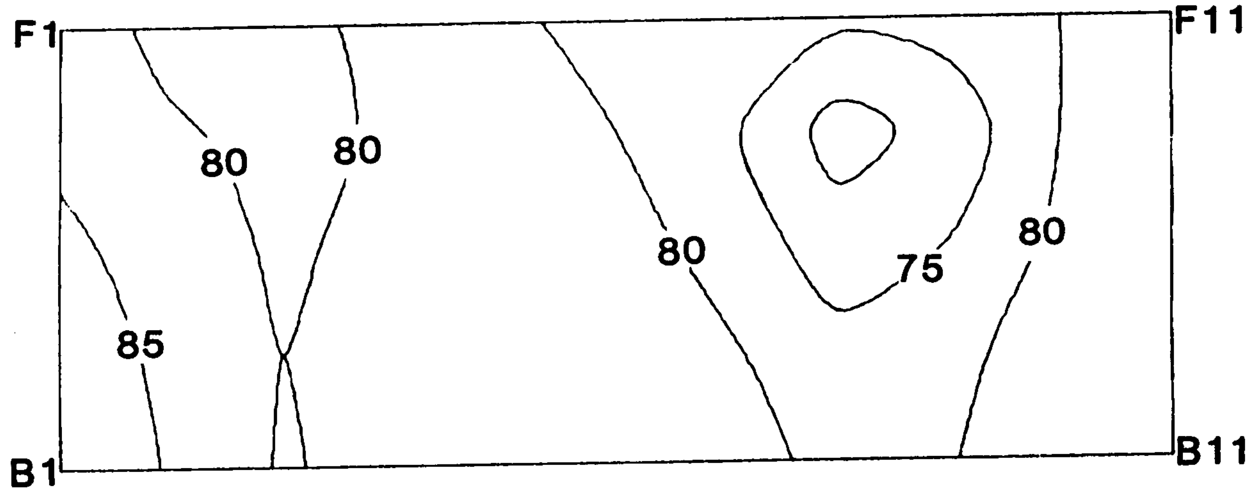

Figure 18.- Lines of constant overall sound pressure level at 58 Hz in the SS/AAA with dummy consoles.

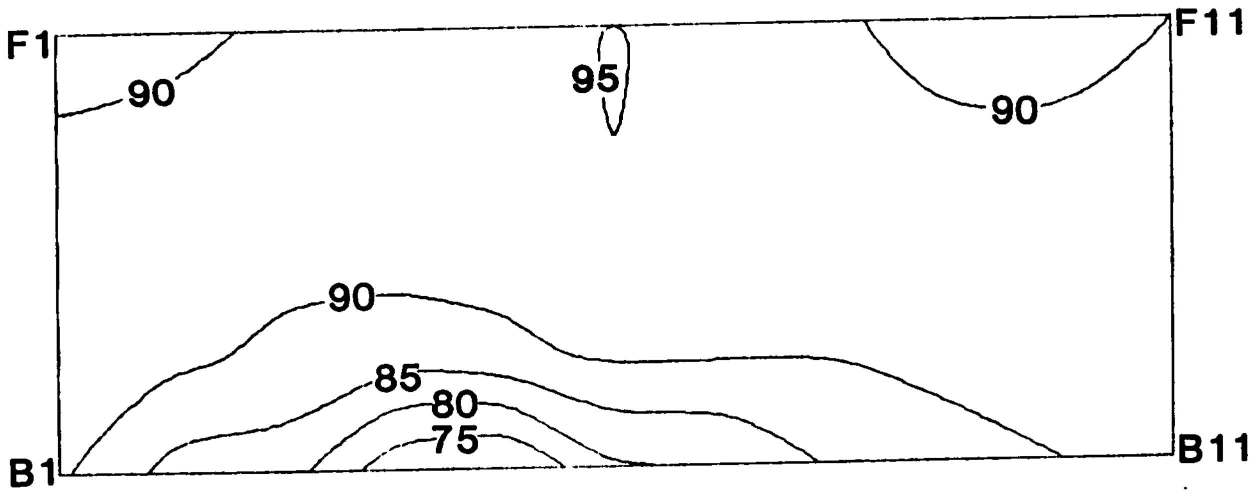

Figure 19.- Lines of constant overall sound pressure level at 80 Hz in the SS/AAA with dummy consoles.

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16. Abstract

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